XVIII. *On the Heat of the Water in the Gulf-ſtream.* *By* Charles Blagden, *M. D. Phyſician to the Army, F. R. S.*

Read April 26, 1781.

ONE of the moſt remarkable facts obſerved in navigating the ocean, is that conſtant and rapid current which ſits along the coaſt of North America to the northward and eaſtward, and is commonly known to ſeamen by the name of the Gulf-ſtream. It ſeems juſtly attributed to the effect of the trade-winds, which blowing from the eaſtern quarter into the great Gulf of Mexico, cauſe there an accumulation of the water above the common level of the ſea; in conſequence of which, it is conſtantly running out by the channel where it finds leaſt reſiſtance, that is, through the Gulf of Florida, with ſuch force as to continue a diſtinct ſtream to a very great diſtance. Since all ſhips going from Europe to any of the ſouthern provinces of North America muſt croſs this current, and are materially affected by it in their courſe, every circumſtance of its motion becomes an object highly intereſting to the ſeaman, as well as of great curioſity to the philoſopher. An obſervation which occurred to me on the ſpot ſuggeſts a new method of inveſtigating a matter that appears ſo worthy of attention.

During a voyage to America in the ſpring of the year 1776, I uſed frequently to examine the heat of ſea-water newly drawn, in order to compare it with that of the air. We made our paſſage

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far to the ſouthward. In this ſituation, the greateſt heat of the water which I obſerved was ſuch as raiſed the quickſilver in FAHRENHEIT's thermometer to 77°½. This happened twice; the firſt time on the 10th of April, in latitude 21° 10′ N. and longitude, by our reckoning, 52° W; and the ſecond time, three days afterwards, in latitude 22° 7′ and longitude 55°; but in general the heat of the ſea near the tropic of Cancer about the middle of April was from 76° to 77°.

The rendezvous appointed for the fleet being off Cape Fear, our courſe, on approaching the American coaſt, became north-weſtward. On the 23d * of April the heat of the ſea was 74°, our latitude at noon 28° 7′ N. Next day the heat was only 71°; we were then in latitude 29° 12′; the heat of the water, therefore, was now leſſening very faſt in proportion to the change of latitude. The 25th our latitude was 31° 3′; but though we had thus gone almoſt 2° farther to the northward, the heat of the ſea was this day rather increaſed, it being 72° in the morning, and 72°½ in the evening. Next day, the 26th of April, at half after eight in the morning, I again plunged the thermometer into ſea-water, and was greatly ſurpriſed to ſee the quickſilver riſe to 78°, higher than I had ever obſerved it, even within the tropic. As the difference was too great to be imputed to any accidental variation, I immediately conceived that we muſt have come into the Gulf-ſtream, the water of which ſtill retained great part of the heat that it had acquired in the torrid zone. This idea was confirmed by the ſubſequent regular and quick diminution of the heat: the ſhip's run for a quarter of an hour had leſſened it 2°; the thermometer,

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* From the difference between civil and nautical time, it becomes neceſſary to obſerve, that the former is always meant in this paper.

at three quarters after eight, being raiſed by ſea-water freſh drawn only to 76°; by nine the heat was reduced to 73°, and in a quarter of an hour more, to 71° nearly: all this time the wind blew freſh, and we were going ſeven knots an hour on a north-weſtern courſe. The water now began to loſe the fine tranſparent blue colour of the Ocean, and to aſſume ſomething of a greeniſh olive tinge, a well-known indication of ſoundings. Accordingly, between four and five in the afternoon ground was ſtruck with the lead at the depth of eighty fathom, the heat of the ſea being then reduced to 69°. In the courſe of the following night and next day, as we came into ſhallower water and nearer the land, the temperature of the ſea gradually ſunk to 65°, which was nearly that of the air at the time.

Unfortunately bad weather on the 26th prevented us from taking an obſervation of the ſun; but on the 27th, though it was then cloudy at noon, we calculated the latitude from two altitudes, and found it to be 33° 26′ N. The difference of this latitude from that which we had obſerved on the 25th, being 2° 23′, was ſo much greater than could be deduced from the ſhip's run marked in the log-book, as to convince the ſeamen that we had been ſet many miles to the northward by the current.

On the 25th at noon, the longitude by our reckoning was 74° W. and I believe the computation to have been pretty juſt; but the ſoundings, together with the latitude, will determine the ſpot where theſe obſervations were made better than any reckoning from the eaſtward. The ſhip's run on the 26th, from nine in the forenoon to four in the afternoon, was about ten leagues on a north-weſt by north courſe; ſoon afterwards we hove-to in order to ſound, and, finding bottom, we went very ſlowly all night, and till noon the next day.

From theſe obſervations, I think, it may be concluded, that the Gulf-ſtream, about the 33d degree of north latitude, and the 76th degree of longitude weſt of Greenwich, is, in the month of April, at leaſt ſix degrees hotter than the water of the ſea through which it runs. As the heat of the ſea-water evidently began to increaſe in the evening of the 25th, and as the obſervations ſhew that we were getting out of the current when I firſt tried the heat in the morning of the 26th, it is moſt probable, that the ſhip's run during the night is nearly the breadth of the ſtream meaſured obliquely acroſs; that, as it blew a freſh breeze, could not be much leſs than twenty-five leagues in fifteen hours, the diſtance of time between the two obſervations of the heat, and hence the breadth of the ſtream may be eſtimated at twenty leagues. The breadth of the Gulf of Florida, which evidently bounds the ſtream at its origin, appears by the charts to be two or three miles leſs than this, excluding the rocks and ſand-banks which ſurround the Bahama Iſlands, and the ſhallow water that extends to a conſiderable diſtance from the Coaſt of Florida; and the correſpondence of theſe meaſures is very remarkable, ſince the ſtream, from well-known principles of hydraulics, muſt gradually become wider as it gets to a greater diſtance from the channel by which it iſſues.

If the heat of the Gulf of Mexico was known, many curious calculations might be formed by comparing it with that of the current. The mean heat of Spaniſh-town and Kingſton in Jamaica ſeems not to exceed 81° *; that of St. Domingo on

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* Hiſtory of Jamaica, London, 1774, vol. III. p. 652, 653. The different obſervations of the heat recorded in that work do not agree together; but thoſe adopted here are taken from that ſeries which appeared to me the moſt correct.

the ſea-coaſt may be eſtimated at the ſame from Monſ. GODIN's obſervations[*]; but as the coaſt of the continent which bounds the gulf to the weſtward and ſouthward is probably warmer, perhaps a degree or two may be allowed for the mean temperature of the climate over the whole bay: let it be ſtated at 82° or 83°. Now there ſeems to be great probability in the ſuppoſition that the ſea, at a certain comparatively ſmall diſtance below its ſurface, agrees in heat pretty nearly with the average temperature of the air during the whole year in that part; and hence it may be conjectured, that the general heat of the water, as it iſſues out of the bay to form the ſtream, is about 82°[†], the ſmall variations of temperature on the ſurface not being ſufficient to affect materially that of the general maſs. At the tropic of Cancer I found the heat to be 77°; the ſtream, therefore, in its whole courſe from the gulf of Florida, may be ſuppoſed to have been conſtantly running through water from 4° to 6° colder than itſelf, and yet it had loſt only 4° of heat, though the ſurrounding water where I obſerved it was 10° below the ſuppoſed original temperature of the water which forms the current. From this ſmall diminution of the heat, in a diſtance, probably of 300 miles, ſome idea may be acquired of the vaſt body of fluid which ſets out of the gulf of Mexico, and of the great velocity of its motion. Numerous obſervations on the temperature of this ſtream, in every part of it, and at different ſeaſons of the year, compared with the heat of the water in the ſurrounding ſeas, both within and without the tropic, would, I apprehend, be the beſt means of aſcertaining its nature, and determining every material circumſtance of its movement, eſpecially if the effect of the current in puſhing ſhips to the northward is carefully attended to, at the ſame time with the obſervations upon its heat.

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[*] Monſ. GODIN's experiments upon the pendulum were made at the Petit Goave. They continued from the 24th of Auguſt to the 4th of September, and the average heat during that time was ſuch as is indicated by 25° of Monſ. DE REAUMUR's thermometer (ſee Mem. Acad. Scienc. 1735, p. 517.). According to Monſ. DE LUC's calculation (ſee Modifications de l'Atmoſpere, vol. I. p. 378.) the 25th degree of Monſ. DE REAUMUR's *true* thermometer anſwers to about the 85th of FAHRENHEIT's; but the average heat in Jamaica during the months of Auguſt and September is alſo 85°; hence we may conclude, that the mean heat for the whole year is nearly the ſame on the ſea-coaſts in both iſlands.

[†] The loweſt calculation of the mean temperature of the gulf is preferred on this occaſion, becauſe of the conſtant influx of new water from the Atlantic Ocean produced by the trade-winds; which water not having been near any land muſt, I think, be ſenſibly cooler than that which has remained ſome time incloſed in the bay. On this ſubject the obſervations made by ALEXANDER DALRYMPLE, Eſq. relative to the heat of the ſea near the Coaſt of Guinea, ought to be conſulted (ſee Phil. Tranſ. vol. LXVIII. p. 394, &c.).

On the 25th of September 1777, as the ſhips which had tranſported Sir WILLIAM HOWE's army up Cheſapeak Bay were returning toward the Delaware, with the ſick and ſtores, they were overtaken, between Cape Charles and Cape Hinlopen, by a violent gale of wind, which, after ſome variation, fixed ultimately at N.N.E. and continued five days without intermiſſion. It blew ſo hard that we were conſtantly loſing ground, and driving to the ſouthward: we alſo purpoſely made ſome *eaſting* to keep clear of the dangerous ſhoals which lie off Cape Hatteras.

The 28th at noon our latitude was 36° 40′ N. and the heat of the ſea all day about 65°. On the 29th our latitude was 36° 2′; we had, therefore, in the courſe of theſe twenty-four hours, been driven by the wind 38 nautical miles to the ſouthward:

ward: the temperature of the ſea continued nearly at 65°. Next day, the 30th, our latitude at noon was 35° 44′, only 18 miles farther to the ſouthward, though in the opinion of the ſeamen aboard, as well as my own, it had blown at leaſt as hard on this as any of the preceding days, and we had not been able to carry more ſail; conſequently it may be concluded, that ſome current had ſet the ſhip 20 miles to the northward. To know whether this was the Gulf-ſtream, let us conſult the thermometer. At half after nine in the forenoon of this day the heat of this water was 76°, no leſs than *eleven* degrees above the temperature of the ſea before we came into the current!

Towards evening the wind fell, and we ſtood N.W. by N. cloſe-hauled. As the ſea ſtill ran very high, and the ſhip ſcarcely went above two knots an hour, we did not make leſs than three points of lee-way on this tack; the courſe we made good, therefore was W.N.W. which, on the diſtance run by noon next day, gave us about ſixteen miles of *northing*; but that day, the 1ſt of October, our latitude was 36° 22′, 38 miles farther to the north than we had been the day before; the difference, 22 miles, muſt be attributed to the Gulf-ſtream. This, however, is only part of the effect which the current would have produced upon the ſhip if we had continued in it the whole four and twenty hours; for, though we were ſtill in the ſtream at five in the afternoon of the 30th, as appeared by the heat of the water being then above 75°, and at eight in the evening the heat being ſtill 74°, yet by ſeven next morning we were certainly got clear of it, the heat of the ſea being then reduced to its former ſtandard of 65°. On this occaſion, therefore, we did not croſs the ſtream, but having fallen-in with it obliquely on the weſtern ſide, we puſhed out again on the ſame ſide as ſoon as the gale abated.

Theſe obſervations having been made three degrees to the northward of my former ones, it is curious to obſerve, that the heat of the Gulf-ſtream was about 2° leſs. The ſeaſons of the year, indeed, were very different; but, perhaps, under ſuch circumſtances that their effects were nearly balanced. In the latter obſervations the meridian altitude of the ſun was leſs; but then a hot ſummer preceded them: whereas in the former, though the ſun's power was become very great, yet the winter had been paſt but a ſhort time. Calculating upon this proportion we may be led to ſuſpect, that about the 27th degree of latitude, which is as ſoon as the ſtream has got clear of the gulf of Florida, it begins ſenſibly to loſe its heat from 82°, the ſuppoſed temperature of the gulf of Mexico, and continues to loſe it at the rate of about 2° of FAHRENHEIT's ſcale to every 3° of latitude, with ſome variation, probably as the ſurrounding ſea, and the air, are warmer or colder at different ſeaſons of the year.

The preceding facts had made me very deſirous of obſerving the heat of the Gulf-ſtream on my paſſage homeward; but a violent gale of wind, which came on two days after we had ſailed from Sandy Hook, diſabled every perſon aboard, who knew how to handle a thermometer, from keeping the deck. The maſter of the ſhip, however, an intelligent man, to whom I had communicated my views, aſſured me, that on the ſecond day of the gale the water felt to him remarkably warm; we were then near the 70th degree of weſt longitude. This agrees very well with the common remark of ſeamen, who alledge, that they are frequently ſenſible of the Gulf-ſtream off Nan-

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tucket ſhoals, a diſtance of more than 1000 miles from the gulf of Florida! According to the calculation I have before adopted of a loſs of two degrees of heat for every 3° of latitude, the temperature of the Gulf-ſtream here would be nearly 73°; the difference of which from 59°, the heat that I obſerved in the ſea-water both before and after the gale, might eaſily be perceived by the maſter of the veſſel. This was in the winter ſeaſon, at the end of December.

An opinion prevails among ſeamen, that there is ſomething peculiar in the weather about the Gulf-ſtream. As far as I could judge, the heat of the air was conſiderably increaſed by it, as might be expected; but whether to a degree or extent ſufficient for producing any material changes in the atmoſphere muſt be determined by future obſervations.

Perhaps other currents may be found which, iſſuing from places warmer or colder than the ſurrounding ſea, differ from it in their temperature ſo much as to be diſcovered by the thermometer. Should there be many ſuch, this inſtrument will come to be ranked among the moſt valuable at ſea; as the difficulty of aſcertaining currents is well known to be one of the greateſt defects in the preſent art of navigation.

In the mean time, I hope the obſervations which have been here related are ſufficient to prove, that in croſſing the Gulf-ſtream very eſſential advantages may be derived from the uſe of the thermometer: for if the maſter of a ſhip, bound to any of the ſouthern provinces of North America, will be careful to try the heat of the ſea frequently, he muſt diſcover very accurately his entrance into the Gulf-ſtream, by the ſudden increaſe of the heat; and a continuance of the ſame experiments will ſhew him, with equal exactneſs, how long he remains in it. Hence he will always be able to make a proper allowance for the number of miles that the ſhip is ſet to the northward, by multiplying the time into the velocity of the current. Though this velocity is hitherto very imperfectly known, for want of ſome method of determining how long the current acted upon the ſhips, yet all uncertainty ariſing from thence muſt ſoon ceaſe, as a few experiments upon the heat of the ſtream, compared with the ſhip's run checked by obſervations of the latitude, will aſcertain its motion with ſufficient preciſion. From differences in the wind, and perhaps other circumſtances, it is probable, that there may be ſome variations in the velocity of the current; and it will be curious to obſerve, whether theſe variations may not frequently be pointed out by a difference in its temperature; as the quicker the current moves, the leſs heat is likely to be loſt, and conſequently the hotter will the water be. In this obſervation, however, the ſeaſon of the year muſt always be conſidered; partly, becauſe it may, perhaps, in ſome degree affect the original temperature of the water in the gulf of Mexico; but principally, becauſe the actual heat of the ſtream muſt be greater or leſs in proportion as the tract of the ſea through which it has flown was warmer or colder. In winter, I ſhould ſuppoſe, that the heat of the ſtream itſelf would be rather leſs than in ſummer; but that the difference between it and the ſurrounding ſea would be much greater; and I can conceive that, in the middle of ſummer, though the ſtream had loſt very little of its original heat, yet the ſea might, in ſome parts, acquire ſo nearly the ſame temperature, as to render it ſcarcely poſſible to diſtinguiſh by the thermometer when a ſhip entered into the current.

Beſides the convenience of correcting a ſhip's courſe, by knowing how to make a proper allowance for the diſtance ſhe is ſet to the northward by the current, a method of determining with certainty when ſhe enters into the Gulf-ſtream is attended with the further ineſtimable advantage of ſhewing her place upon the ocean in the moſt critical ſituation: for, as the current ſets along the coaſt of America at no great diſtance from ſoundings, the mariner, when he finds this ſudden increaſe of heat in the ſea, will be warned of his approach to the coaſt, and will thus have timely notice to take the neceſſary precautions for the ſecurity of his veſſel. As the courſe of the Gulf-ſtream comes more to be accurately known, from repeated obſervations of the heat and latitudes, this method of determining the ſhip's place will be proportionably more applicable to uſe. And it derives additional importance from the peculiar circumſtances of the American coaſt, which, from the mouth of the Delaware to the ſouthernmoſt point of Florida, is every where low, and beſet with frequent ſhoals, running out ſo far into the ſea that a veſſel may be aground in many places where the ſhore is not to be diſtinguiſhed even from the maſt-head. The gulf-ſtream, therefore, which has hitherto ſerved only to increaſe the perplexities of ſeamen, will now, if theſe obſervations are found to be juſt in practice, become one of the chief means of their preſervation upon that dangerous coaſt.